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Irradiation-Induced Amorphous Structures Studied by Electron Diffraction Radial Distribution Function Analysis

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Radiation effects in solids are one of the important issues in the research fields ranging from microelectronics devices to nuclear fusion reactors. Energetic particles, such as ions, neutrons, and electrons, induce extensive damage, and finally amorphization occurs. Knowledge of amorphous structures is of technological importance for understanding the amorphization mechanisms under radiation environments. Atomic radial distribution function analysis using diffraction techniques is a standard method for studying short-range order of amorphous materials. Recent progresses in electron microscopy techniques make it possible to perform a quantitative analysis of electron diffraction intensities. For example, energy-filtering TEM enables us to remove the contribution of the inelastically-scattered electrons from the intensity profile of electron diffraction patterns. Also, modern recording materials, such as slow scan charge-coupled-device camera and imaging plate, have a higher degree of linearity and a wider dynamic range in recording electron intensities as compared with conventional TEM photographic films. Here, we report radial distribution functions of ion-beam-induced amorphous phases using electron diffraction techniques.

Fig. 1 shows damage recovery processes of SiC irradiated with 10 MeV Au ions to a fluence of 10^{15} cm^{-2} at room temperature. An amorphous layer with a thickness of ~2.7 mm is formed in as-irradiated SiC [Fig. 1(a)]. Prior to recrystallization [Fig. 1(c)], it is apparent that the amorphous layer itself shrinks in annealing [Fig. 1(b)]. Fig. 1(d) shows reduced interference functions, $F(Q)$, of amorphous SiC as a function of annealing temperature. Very weak intensity profiles are recorded well up to Q~300 nm^{-1}. It is apparent that the amplitude of the peaks, especially within Q=120 nm^{-1}, increases with annealing temperature. Fig. 1(e) shows reduced radial distribution functions, $G(r)$, extracted by the Fourier transform of the $F(Q)$. Two prominent peaks exist at ~0.19 and ~0.31 nm, which can be compared with the first nearest neighbor (Si-C: 0.188 nm) and the second nearest neighbor distances (Si-C-Si, C-Si-C: 0.307 nm) of crystalline SiC. In addition, there exist two subpeaks located at ~0.15 and ~0.23 nm, which correspond to C-C and Si-Si bond lengths, respectively. These subpeaks decrease with thermal annealing, but the annihilation speeds are different: Si-Si bonds decrease more rapidly than C-C bonds. This means that the number of longer bonds decreases with structural relaxation. We propose that this unbalance in annihilation speed between the homonuclear bonds results in the significant volume reduction of amorphous SiC on thermal annealing.

Fig. 2(a) shows a cross-sectional bright-field TEM image of Si irradiated with 120 keV Fe ions to a fluence of $4x10^{17}$ cm^{-2} at cryogenic temperature. A layered amorphous indicated by A and B is formed on the substrate (C). A clear difference exists in diffraction patterns obtained from layers A and B: the diameter of the first halo ring in the former [Fig. 2(b)] is larger than that in the latter [Fig. 2(c)]. Atomic pair-distribution functions, $g(r)$, of layers A (solid line) and B (dashed line) are indicated in Fig. 2(d). The first and second peaks for the $g(r)$ obtained from layer B are located at the atomic distances of ~0.236 and 0.379 nm, respectively, which are in good agreement with those of amorphous Si. On the other hand, the amorphous phase of layer A possesses the longer bonds than that of layer B: 0.239 nm for the first peak and 0.428 nm for the second one. It should be noted that the

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first peak is asymmetric and a characteristic shoulder is observed in the large-*r* region of the first peak. The position of the first main peak and shoulder can be explained from the atomic correlation distances of crystalline iron silicides. The formation of the layered amorphous Si and iron silicides are attributed to sputtering effects during ion irradiation.

References

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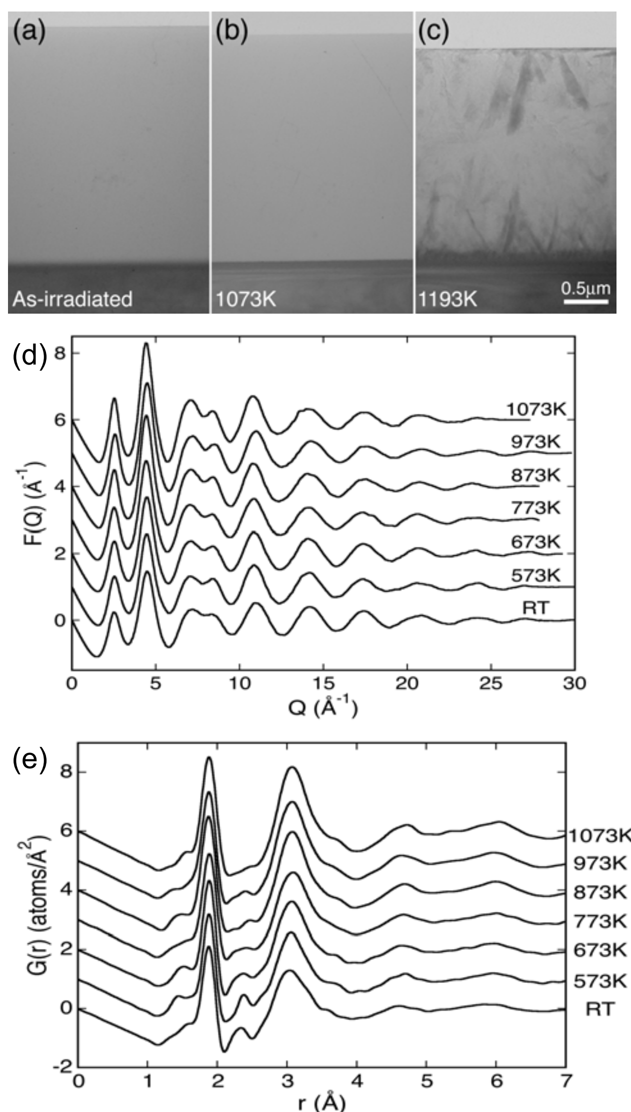

Fig. 1. Damage recovery processes of ion-irradiated SiC. (a-c) Cross-sectional TEM images, (d) reduced interference functions, and (e) reduced radial distribution functions.

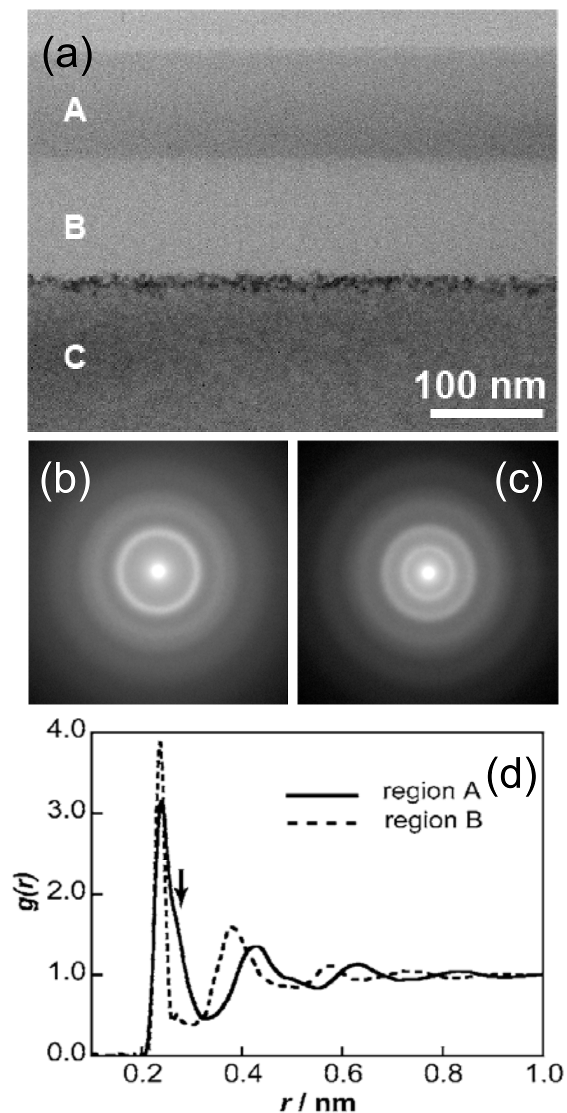

Fig. 2. Fe ion irradiated Si substrate. (a) Cross-sectional TEM image, (b,c) electron diffraction patterns, and (d) atomic pair-distribution functions.

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